Body Mass Index and Old Age Survival: A Comparative Study Between the Union Army Records and the NHANES-I Epidemiological Follow-up Sample[1]

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Abstract

In this paper, I made a historical investigation of the BMI-mortality association among white male Americans through a comparative survival analysis between the Union Army Records and the NHANES-I Epidemiological Follow-up sample. The results indicate that the association between BMI and old age survival is historically dynamic, rather than stable. With the whole American population having moved into a higher BMI regime, the optimal BMI has also experienced a substantial upward shift, from (20.4-22.0) in the late 19th century to (24.9-26.9) in early 1970s. In both samples, those who were seriously underweight are associated with a higher risk of mortality. The mortality penalty associated with the highest BMI quintile has declined substantially since the late 19th century. The implications of these findings to the future trend in old age mortality among white male Americans are discussed.

Introduction

Numerous studies in medical science and economic history have reported a patterned impact of adulthood body mass index (BMI, also called Quetelet's Index, calculated as weight in kilograms divided by height in meters squared) on mortality, with extreme low and high BMI associated with a higher risk of mortality (Waaler 1984; Calle et al. 1999; Durazo et al. 1998; Engleland et al. 2003; Costa 1993; Fogel and Costa 1997; Allison et al. 1997; Dorn et al. 1997). However, to what extent this causal relationship is relevant in predicting old age mortality still remains controversial. Studies often reported different optimal BMI or different patterns of association between BMI and old age survival. Constructive comparisons between these studies become difficult, because they usually differ in the target population, age range of the sample, years of follow-up, methodology, or controlled variables in the model.

In this paper, I will explore the impact of BMI on old age survival through a comparative study between the Union Army records and the 1971-75 National Health and Nutritional

Examination Survey (NHANES) Epidemiological Follow-up sample[2]. By applying the same survival analysis to both data sets, the main research purpose of this paper is to reveal whether and how the association between BMI and old age survival among white male Americans has changed since the late 19th century. This is a period when the whole American population experienced an unprecedented decline in mortality and a dramatic increase in BMI in virtually all age groups. It thus becomes meaningful to explore whether the impact of BMI on old age survival observed in the late 19th century still holds true today and to what extent. In other words, has the robustness of the association between BMI and old age mortality changed over time? Has the optimal BMI also shifted upward as the whole population has moved into a higher BMI regime? To take the ongoing upward trend in BMI into consideration, a probe into these questions can shed some light on the future old age mortality among white male Americans.

The paper is composed of three parts. Firstly, I briefly review the historical changes in BMI among white male Americans since the 19th century using the Union Army Records and three waves of NHANES data. In the second part, survival analyses will be applied to two sub-samples consisting of white male Americans who were examined at age 50 to 59, with one examined in 1891 and the other examined between 1971 and 1974. The follow-up period is 18 years for both sub-samples. Finally, in the discussion and conclusion part, I summarize the main findings and discuss their implications to the future trend in old age mortality among white male Americans.

1. Changes in Adulthood BMI among White Male Americans since the 19th Century

The past three centuries witnessed an unprecedented increase in both the height and body weight of Americans. It has been estimated that the mean height of white, Native-born male Americans increased from around 171cm in the early 18th century to 177cm in the late 20th century, and most of the increase was achieved during the 20th century (Fogel, 1986; Costa and Steckel, 1995). Compared with the abundance of data on height, information on the weight of Americans prior to the 19th century is scarce. Available historical evidence from European nations suggests that the average weight of English males in their thirties around

[2] I merged NHANES first wave (1971-75) with its 1992 vital status follow-up.

1790 was about 61 kg and the corresponding figure for French males may have been only about 50 kg (Fogel and Costa, 1997). Since the majority of the immigrants in America prior to 19th century came from England, it can be inferred that the average BMI for American males in their thirties in the late 18th century was around 20.6 ($61/(1.72)^2$).

1.1 Data Used in the Description of BMI Trend

Due to the scarcity of data, a reliable estimate of BMI distribution among white male Americans in the 19th century did not become feasible until the release of the Union Army Records dataset by the Center for Population Economics at the University of Chicago. After the Civil War ended, as required by the Pension Bureau, the Union Army veterans had their physical examinations conducted by doctors, the result of which was used to evaluate the amount of pension they should receive. 95 percent of the veterans in the pension records had their first examination before 1900. As an integrated part of the Union Army Records, the Surgeon's Certificate data collected information on height, weight, age at examination, and detailed morbidity and mortality records for about 14, 000 Union Army veterans. Analysis of possible sample selection bias indicated that the Surgeon's Certificate sample is generally representative of the population of white recruits into the Union Army (Fogel, 2000).

Table 1: Five Data Sets Used in the Descriptive Analysis of BMI Trend (White males only)

Data Sets	Time of Data Collection	Sample Size	Weighted Sample	Longitudinal
The Surgeon's Certificate Records of the Union Army	1866-1928	14,459	No	Yes
NHANES-I with Follow up	1971-74 with Follow up to 1992	7,004	Yes	Yes
NHANES-III	1988-94	5,470	Yes	No
NHANES 1999-2000	1999-2000	1,537	Yes	No
The Waaler Sample	1963-75 with Follow up to 1987	876,278	No	Yes

Table 1 gives a brief introduction to the five data sets used in my description of the BMI trend among white males since the 19th century. The Union Army Surgeon's Certificate data is a longitudinal, unweighted sample, with a sample size larger than each of the NHANES waves. The three NHANES datasets are all weighted samples, among which only the

NHANES-I is longitudinal, with vital status follow-up to 1992. Comparisons between the Union Army Surgeon's certificate data and the three waves of NHANES can help to reveal how BMI has changed among white male Americans since the 19^{th} century. In addition, since I am also interested in comparing the BMI distribution of contemporary white male Americans with their European counterparts, the Waaler sample that covers the whole male population aged 15 and above in Norway between 1963 and 1975 was also incorporated in the descriptive analysis below.

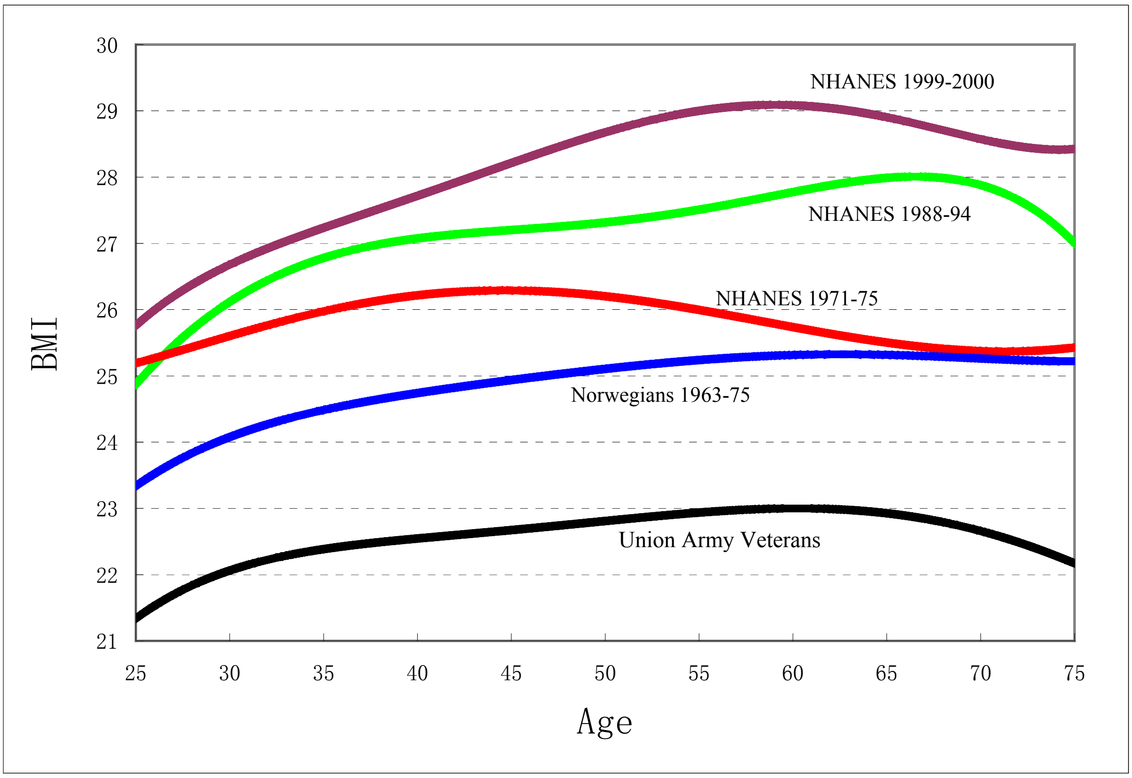
1.2 BMI Trend since the 19^{th} Century: A Descriptive Analysis

Since BMI is sensitive to nutritional intake, the age-adjusted average BMI of a certain population can change in different historical periods when food availability and composition changes, or when the epidemiological environment changes. The technophysio evolution theory (Fogel and Costa, 1997) proposes that in the past three hundred years environmentally induced changes, which were made possible by numerous advances in technology, have increased human body size by over 50 per cent. This theory actually establishes a new perspective of exploring the factors behind mortality decline during the past three centuries by associating increase in body size (as an indicator of improved nutritional status or of a more favorable health environment) with mortality decline.

To see how BMI has changed among white male since the 19^{th} century, I calculated the average BMI at each age between age 25 and 75 in each of the five samples, as indicated in Figure 1. In order to reduce noises caused by the relative smaller sample sizes of the three NHANES samples, fifth order polynomial fitting was utilized to smooth the BMI distributions over age for all the five samples. A detailed reading of Figure 1 elicits several important findings.

Firstly, it is obvious that the average BMI of white male Americans has experienced a remarkable increase in virtually all age groups between age 25 and 75 since the 19^{th} century. For most of the age groups in the Union Army Surgeon's Certificate data, the average BMI is between 22 and 23, while the corresponding figure for the 1999-2000 NHANES is well above 27.

Figure 1: BMI at Different Ages in the Five Samples



Note: Calculations in the three NHANES data were based on weighted sample.

Secondly, comparisons between the three waves of NHANES data indicate a steady increase in adulthood BMI among white male Americans since the 1970s. At most ages, average BMI in later waves of NHANES was notably higher than that in the former waves. A little extrapolation of this trend would suggest that the increase in average BMI among white male Americans is still ongoing, and probably will not cease in the near future.

Thirdly, a comparison between the NHANES-I and the Waaler sample suggests that white male Americans in the early 1970s, on average, had a higher BMI than their counterparts in Norway. The difference becomes more salient for those younger than 55 in the two countries. This trend continues up to today. Obesity rate among male Americans now is higher than that in most European countries (Komlos and Baur, 2003).

The trend in BMI becomes more informative when it was scrutinized in terms of the classification standard adopted by the World Health Organization in 1997: underweight (BMI<18.5), normal weight (18.5≤BMI<25), overweight (25≤BMI<30), and obesity (BMI≥30). In Table 2 below, the proportion of each BMI category in each of the five samples is given. As a summarized indicator, age-adjusted average BMI between 25 and 74 was also calculated for each sample. Since BMI changes with age, to control for the influence of age structure, all calculations of rates were adjusted to the U.S. 2000 standard population age structure (5-year age groups from age 25 to 74).[3] Sample weights for the three NHANES data sets were applied.

Table 2: Age-Adjusted Distribution of Adulthood BMI In the Five Samples (%)

BMI Categories	Union Army 1866-1928	NHANES-I 1971-75	NHANES-III 1988-94	NHANES 1999-2000	Waaler Sample 1963-75
Underweight	3.9	2.1	0.5	1.5	0.8
Normal	80.4	40.0	35.3	29.6	54.8
Overweight	13.3	45.7	43.7	40.7	39.0
Obesity	2.4	12.2	20.5	28.2	5.3
Age-adjusted Average BMI	22.6	25.9	27.0	28.0	24.8

Consistent with what was found in Figure 1, age-adjusted average BMI among white male Americans has increased by almost one quarter since the 19th century, from 22.6 in the Union Army Surgeon's Certificate Records to 28.0 in the 1999-2000 NHANES. In other words, on average, adult white male Americans today are in the category of overweight, closer to obesity than to normal weight. The age-adjusted average BMI from the NHANES-I and the Waaler sample confirmed that white male Americans in the 1970s on average had higher BMI than their counterparts in Norway (25.9>24.8).

Despite the declining prevalence of underweight, a dramatic percentage increase in both overweight and obesity among white male Americans since the 19th century indeed raises health concerns. The percentage of underweight decreased from 3.9 percent in the Union Army Records to 1.5 percent in the 1999-2000 NHANES. However, due to its small proportion in all five samples, percentage change in the underweight category has little effect on the overall trend of BMI. The remarkable changes lie in the increased prevalence of overweight and obesity among today's white male Americans. The proportion of overweight

[3] Source: The U.S. Census Bureau, Internet Release Date: 10/03/2001.

increased from 13.3 percent among the Union Army veterans to 40.7 percent among contemporary white male Americans, a 206 percent of increase. The corresponding figure for percentage change in obesity is more dramatic, from 2.4 to 28.2, an alarming 1, 075 percent of increase! At the same time, the proportion of normal weight (presumably more favorable to health), declined from 80.4 percent to 29.6 percent. Considering the established association between overweight, especially obesity, and higher risk of certain diseases such as hypertension, high blood cholesterol, type 2 diabetes, coronary heart disease, and other diseases (NIH, 1998), there are adequate reasons to worry about such an ongoing trend.

2. BMI and Old Age Survival: Comparative Survival Analysis Between the Union Army Surgeon's Certificate Records and the NHANES-I with Its 1992 Vital Status Follow-up

After a review of historical changes in BMI since the 19th century, the important research question that this paper tries to address can be posed: what does the upward trend of BMI imply to the future old age mortality among white male Americans? My strategy of coping with this question is to apply comparative survival analysis between the Union Army Surgeon's Certificate data and the NHANES-I with its 1992 Status Follow-up data, and see how the association between BMI and old age survival has changed since the 19th century. If the association between BMI and old age mortality is robust and persistent throughout the last century, then this confirmed association, in conjunction with the trend in BMI, can help to predict future old age mortality among white male Americans. Otherwise, if it is found that the pattern of the association has changed over last century, the implication of these changes to the future trend in old age survival can also be investigated.

Before proceeding into the survival analysis, a theoretical question needs to be clarified: Why can BMI be associated with old age survival? Firstly, it has been well established that BMI can be used as a rough indicator of current nutritional status. Different amount and compositions of nutrition intake are expected to influence a person's BMI. Secondly, and more importantly, BMI has a close association with certain types of diseases. For example, being obese usually implies a higher risk for diseases such as hypertension, coronary heart disease, or diabetes. At the same time, some diseases such as certain types of cancer, diabetes, hyperthyroidism etc., might also have a substantial impact on BMI. Thus, it is safe to assume that, at the micro level, an individual's BMI can be regarded as a rough indicator of his/her current nutritional status or his/her risk of BMI-related morbidity; at the macro level, the average BMI of a population or the change of it, after controlling for the age structure, can be expected to reflect the favorableness of the nutritional and epidemiological environment where the population survives.

Table 3: Two Sub-Samples Used in Survival Analysis

Data Sets	Time at Examination	Age at Examination	Years of Follow-up	Sample Size	Mean Height	Mean BMI
The Union Army Survival Sample	1891	50-59 (Mean=54.5)	18	794	67.9	23.0
NHANES-I Survival Sample	1971-74	50-59 (Mean=54.2)	18	603	68.5	26.0

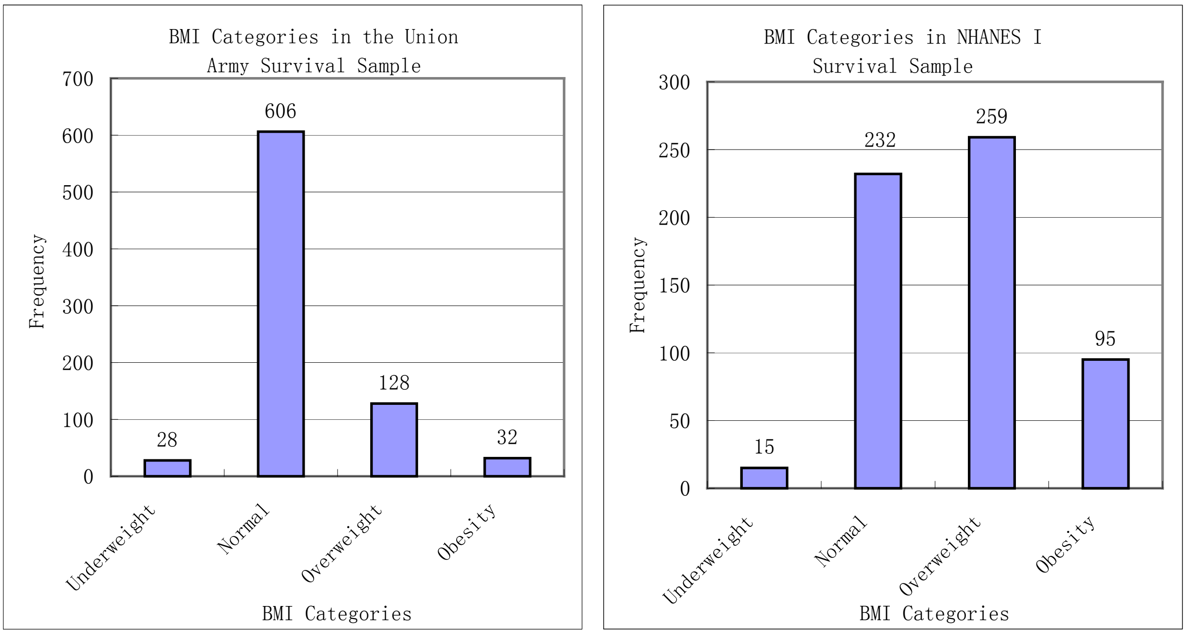
Table 3 gives a brief introduction to the two sub-samples (later termed as 'Union Army survival sample' and 'NHANES-I survival sample') I will use in the survival analysis. The two survival samples resemble each other in terms of age at examination, years of observation, and sample size. In both survival samples, age at examination was confined between age 50 and 59, with a follow-up period of 18 years. These proximities, to a certain extent, provide a controlled setting for subsequent survival analysis and make it as comparable as possible. The purpose of a comparable survival analysis is to reveal how the association between BMI and old age survival differs across the two survival samples so that we can understand how it has evolved since the late 19th century.

2.1 BMI and Old Age Survival: A Bivariate Survival Analysis

The mortality rate during the observation period in the Union Army survival sample is much higher than that in the NHANES-I survival sample. 18 years after the examination, 50.5 percent of the Union Army veterans survived. The corresponding percentage for white male Americans in the NHANES-I survival sample is 62.3 percent.

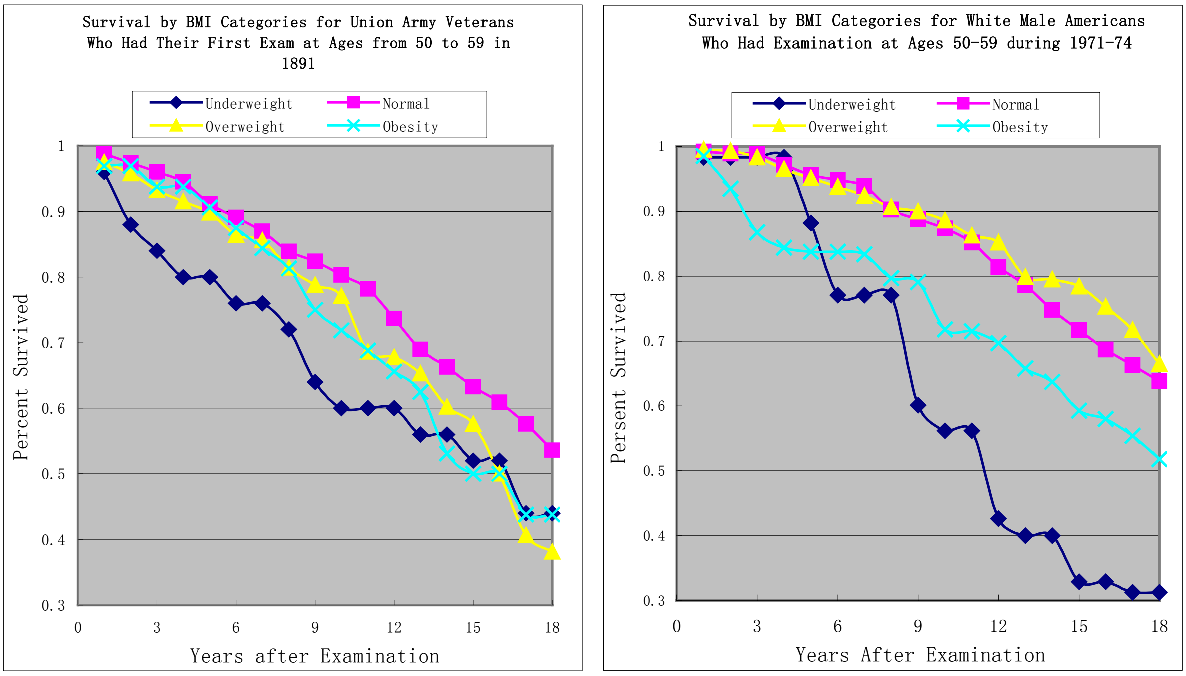
The focus of the analysis in this part is to see how mortality rates differed across BMI categories in the two survival samples. I first checked the distribution of BMI in the two survival samples. As indicated in Figure 2, the two survival samples each have a distinct distribution of BMI. While veterans in the Union Army survival sample were predominantly in the category of normal weight, more than 50 percent of the NHANES-1 survival sample was in the categories of overweight and obesity.

Figure 2: BMI Four Categories in the Two Survival Samples



So how did mortality differ across BMI categories in the two survival samples? The answer lies in Figure 3 below. A detailed comparison between survival curves in the two samples revealed several intriguing findings:

Figure 3: Survival by BMI Categories in the Two Survival Samples



Firstly, in both samples and in most of the observation years, white male Americans with normal weight had the lowest (or almost the lowest) mortality, while those who were underweight at the examination had the highest mortality. Among Union Army veterans who had normal weight at the examination, 53.6 percent survived the 18 years observation period. The corresponding figure for those underweight veterans is 44 percent. That is to say, the survival gap is 9.6 percent between those veterans with the most favorable BMI and those with the least favorable BMI. This gap becomes more dramatic among white male Americans in the NHANES-I survival sample, with a gap of 32.5 percent (63.8-31.3=32.5).

Secondly, there is evidence suggesting that the mortality risk for being overweight has declined dramatically since the late 19th century. While overweight Union Army veterans suffered a much higher mortality risk than normal weight veterans, overweight white male Americans in the NHANES-I survival sample did not. Actually their mortality level was pretty close to those with normal weight. This tends to suggest that optimal BMI has increased since the late 19th century.

Thirdly, in both survival samples, the mortality risk for being obese is lower than that for being underweight, but substantially higher than that for having normal weight. A notable difference, however, is that obese white male Americans in the NHANES-I survival sample had lower mortality rate than their Union Army counterparts. 43.8 percent of obese Union Army veterans survived the 18 years of observation, while the corresponding figure for those in the NHANES-I survival sample is 51.8 percent.

It must be noted that the lower overall mortality observed in the NHANES-I survival sample does not necessarily mean it had a more favorable BMI distribution than the Union Army survival sample. My calculation indicates that, given the mortality level observed in each BMI category in the NHANES-I survival sample, if the BMI distribution was changed to the one in the Union Army survival sample, that is to say, if the proportion of each BMI category in the NHANES sample was made the same as that in the Union Army survival sample, the overall mortality during the 18 years of observation would be 1 percent less, from 0.377 to 0.373. Conversely, were the BMI distribution in the Union Army survival sample switched to the one in the NHANES-I survival sample, the overall mortality would have increased by 11.2 percent, from 0.495 to 0.550. Given the higher prevalence of overweight and obesity among white male Americans since the 1970s as I stated earlier, these results suggest that today's BMI distribution among white male Americans is even more detrimental to old age survival than what it was a century ago.

2.2 **BMI and Old Age Survival: Cox Proportional Hazard Modeling**

Despite the intriguing findings revealed, the bivariate analysis above has several limitations. Firstly, it failed to control for any other relevant variables such as age at examination, marital status, and height that might also have an impact on old age survival. Secondly, since the bivariate analysis did not provide a significant test, we do not know whether the mortality difference between BMI categories is statistically significant or not. Finally, one limitation of classifying BMI into four categories is that some categories have too few cases (<50, as indicated in Figure 2), and therefore the reliability of the results is questionable.

As one of the most popular analytic tools in survival analysis, the Cox Proportional Hazard (CPH) modeling can be utilized to overcome the first and second limitation mentioned above. A big advantage of CPH modeling is that it can simultaneously estimate the effect of each independent variable in the model on the hazard rate without specifying the baseline hazard function. The basic mathematical equation can be expressed as:

$$h(t) = [h_0(t)] \exp(b_1x_1+b_2x_2+\ldots b_nx_n)$$

Where:

$h(t)$ = the hazard function at time t. In this paper it represents mortality risk at time t

$h_0(t)$ = the baseline hazard, resembling the constant in multivariate regression analysis

$x_1, x_2 \ldots x_n$ = independent variables in the model

$b_1, b_2 \ldots b_n$ = estimated coefficients in the CPH model. For example, if x_1 is a continuous variable, b_1 can be interpreted as: 'For each unit of increase in x_1, the relative hazard becomes $\exp(b_1)$ as much, controlling for the other independent variables in the model.'

An important assumption made by CPH modeling is the proportionality assumption, which assumes that changes in the values of the independent variables will produce proportionate changes in the hazard function, independent of time. In other words, any two cases are expected to have a constant ratio of hazard over the observation period, if there are no time-dependent covariates in the model.

I then ran the same six CPH models in both the Union Army survival sample and the NHANES-I survival sample. A survival plot test using BMI quintiles as strata for the first model suggests that the proportionality assumption largely holds in both samples, although the fit is better in the NHANES-I survival sample. The results of the six CPH models for both samples were presented in Table 4 and 5 in the next two pages.

Table 4: Results of the Six Cox Proportional Hazard Models: the Union Army Survival Sample[4]

Covariates	Cox Proportional Hazard Models					
	Model 1 to 3: All Deaths Included			Model 4 to 6: Deaths After the 5th Year of Follow-up		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Age at Exam	0.098***	0.094***	0.095***	0.106***	0.106***	0.103***
	(0.020)	(0.019)	(0.020)	(0.023)	(0.023)	(0.023)
BMI 1st Quintile[5]	*0.165*	*0.165*	0.150	0.171	0.173	0.157
	(0.100)	(0.101)	(0.101)	(0.112)	(0.112)	(0.112)
BMI 2nd Quintile	- 0.249*	- 0.249*	- 0.246*	*- 0.234*	*- 0.233*	*- 0.228*
	(0.115)	(0.115)	(0.115)	(0.126)	(0.126)	(0.126)
BMI 3rd Quintile	- 0.097	- 0.097	- 0.078	- 0.115	- 0.114	- 0.094
	(0.106)	(0.106)	(0.116)	(0.118)	(0.118)	(0.118)
BMI 4th Quintile	- 0.111	- 0.111	- 0.113	- 0.163	- 0.163	- 0.166
	(0.106)	(0.106)	(0.106)	(0.120)	(0.120)	(0.120)
BMI 5th Quintile	0.291**	0.292**	0.287**	0.340**	0.338**	0.331**
	(0.097)	(0.097)	(0.097)	(0.106)	(0.107)	(0.107)
Height		0.001	0.007		- 0.008	- 0.001
		(0.021)	(0.022)		(0.024)	(0.024)
Being Farmer			- 0.286**			- 0.315**
			(0.205)			(0.116)
Number of Cases	794	794	794	682	682	682
Chi-square	39.43 (df=5)	39.44 (df=6)	47.137 (df=7)	37.90 (df=5)	38.00 (df=6)	45.59 (df=7)

4 *** p<.001; ** p<.01; * p<.05. Italic coefficients means significant at α=0.1 level.

5 Deviation contrast was applied in all the models. Therefore, the coefficient for each BMI quintile reflects how much its effect deviated from the overall average effect of BMI.

Table 5: Results of the Six Cox Proportional Hazard Models: NHANES-I Survival Sample[6]

Covariates	Cox Proportional Hazard Models					
	Model 1 to 3: All Deaths Included			Model 4 to 6: Deaths After the 5th Year of Follow-up		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Age at Exam	0.031	0.030	0.026	0.034	0.033	0.030
	(0.022)	(0.022)	(0.022)	(0.024)	(0.024)	(0.024)
BMI 1st Quintile[7]	0.268*	0.270*	0.231*	0.317**	0.319**	0.288*
	(0.113)	(0.113)	(0.114)	(0.122)	(0.123)	(0.123)
BMI 2nd Quintile	- 0.098	- 0.080	- 0.079	- 0.120	- 0.092	- 0.092
	(0.124)	(0.126)	(0.126)	(0.137)	(0.138)	(0.138)
BMI 3rd Quintile	- 0.363**	- 0.358**	- 0.350**	- 0.383**	- 0.373*	- 0.367*
	(0.136)	(0.136)	(0.136)	(0.149)	(0.149)	(0.149)
BMI 4th Quintile	- 0.032	- 0.036	- 0.028	0.027	0.021	0.026
	(0.121)	(0.121)	(0.121)	(0.149)	(0.149)	(0.149)
BMI 5th Quintile	0.225*	*0.204*	0.226*	0.160	0.126	0.145
	(0.115)	(0.117)	(0.117)	(0.129)	(0.131)	(0.131)
Height		- 0.026	- 0.018		- 0.039	- 0.033
		(0.024)	(0.024)		(0.026)	(0.026)
Being Married			- 0.695***			- 0.618***
			(0.195)			(0.179)
Number of Cases	603	603	603	555	555	555
Chi-square	16.38 (df=5)	17.63 (df=6)	38.57 (df=7)	14.83 (df=5)	17.23 (df=6)	30.18(df=7)

6 *** p<.001; ** p<.01; * p<.05. Italic coefficients means significant at α=0.1 level.

7 Deviation contrast was applied in all the models. Therefore, the coefficient for each BMI quintile reflects how much its effect deviated from the overall average effect of BMI.

A notable change in the CPH models above, compared to the previous bivariate analysis, is that BMI has been categorized into BMI quintiles, rather than four categories. There are two considerations behind this change. One is that this avoids the problem of too small of a category size, because each of the BMI quintiles has one fifth of the total survival sample. The other consideration is that if there did exist an optimal BMI in terms of old age survival in the two samples, categorizing BMI into quintiles can give a more precise estimate of optimal BMI than four-category BMI. Table 6 provides a description of BMI quintiles in both survival samples. In each of the BMI quintile, the mean value in the NHANES-I survival sample is substantially higher than that in the Union Army survival sample.

Table 6: BMI Quintiles in the Two Survival Samples

BMI	The Union Army Survival Sample				The NHANES-I Survival Sample			
Quintiles	Range	Mean	Std. dev.	N	Range	Mean	Std. dev.	N
1st	14.3-20.6	19.3	1.17	158	15.4-22.7	20.5	1.72	120
2nd	20.6-21.9	21.2	0.39	156	22.7-24.9	23.8	0.64	121
3rd	21.9-23.2	22.5	0.39	161	24.9-26.6	25.9	0.53	121
4th	23.2-25.0	24.0	0.54	160	26.6-29.0	27.6	0.74	121
5th	25.0-41.1	27.9	2.83	159	29.0-43.9	32.2	3.02	120

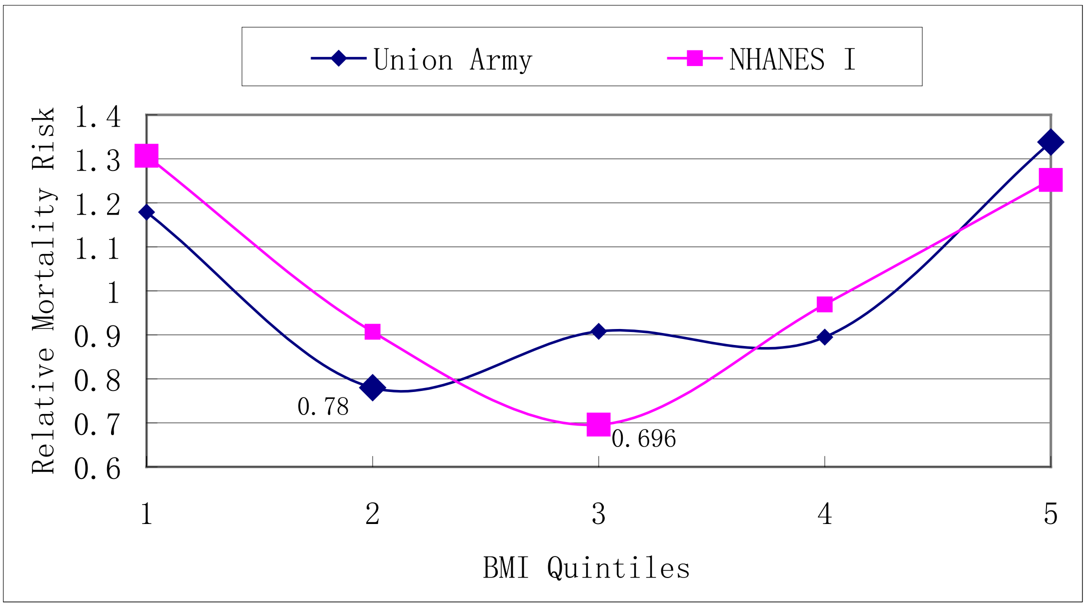
The six models presented in Table 4 and 5 constitute a sensitivity analysis for the association between BMI and old age mortality under different situations. While Model 1, 2, and 3 were based on the survival samples with all deaths included, Model 4, 5, and 6 targeted to survival samples with deaths in the first five years excluded. The purpose here is to control for possible spurious causation in the sense that for persons who had serious diseases at the examination, their short survival after the examination can be viewed more as a result of the diseases they had than of the effect from their BMI. The only difference between Model 1 and 2, and between Model 3 and 4, is that the latter incorporated height into the model. In the Union Army survival sample, on the basis of Model 2 and 4, Model 3 and Model 6 bring in whether being farmer at enlistment. For the NHANES-1 survival sample, Model 3 and Model 6 were constructed after marital status at examination was added[8].

[8] The reason of using different variables in the two survival samples for Model 3 and Model 6 is that I failed to find information on marital status at examination in the Union Army survival sample.

My interpretation of the Cox regression results in Table 4 and 5 starts with the effect of BMI at examination.

Firstly, and most importantly, there is clear evidence suggesting that the optimal BMI in terms of survival after one's fifties has experienced a substantial upward shift since the late 19th century. This upward shift was reflected in both the relative and absolute terms of BMI. For the Union Army veterans, the lowest mortality risk was observed in the second BMI quintile (20.6-21.9), with a mean of 21.2. Given the standard deviation in Table 6, the 95% confidence interval for optimal BMI among the Union Army veterans becomes (20.4, 22.0), and this optimal BMI is robust across all six models. For those in the NHANES-I survival sample, optimal BMI was observed in the third quintile (24.9-26.6), with a mean of 25.9. This observation is also true in all of the six models. The corresponding 95% confidence interval for optimal BMI becomes (24.9, 26.9) in the NHANES survival sample. To take Model 1 as an example, compared with the overall average mortality risk, the mortality risk for Union Army veterans who had a BMI between 20.6 and 21.9, is 0.78 (=exp(-.249)) times as much, controlling for the other explanatory variables in the model. The corresponding figure for those who had BMI between 24.9 and 26.6 in the NHANES-I survival sample is 0.7 (=exp(-.363)) times as much.

Figure 4: Relative Mortality Risk by BMI Quintiles Based on Model 1



Note: 1. BMI 1st to 5th quintile: lowest to highest.

2. Larger size of data point indicates the effect is significant at α=0.05 level.

The upward shift of optimal BMI can also be revealed by Figure 4 above. Despite this difference, the U-shaped mortality risk curve largely holds in both samples.

Secondly, being in the lowest BMI quintile is associated with higher mortality risk in both survival samples. The effect is statistically significant in all of the six models in NHANES-I survival sample, and marginally significant (at α=0.1 level) in the first two models in the Union Army survival sample. To take Model 4 in the NHANES-I survival sample as an example, after deaths in the first five years have been excluded, mortality risk for those white male Americans who had a BMI between 15.4 and 22.7 in their fifties becomes 1.37 (=exp (0.317)) times the average overall mortality risk, holding the other variables in the model constant. The corresponding figure in the Union Army survival sample is 1.19 times, but the effect is not statistically significant. This suggests that, for white male Americans, those who are seriously underweight in their fifties are expected to have higher mortality risk in the following 18 years, and this effect has become more salient since the late 19^{th} century.

Thirdly, mortality risk associated with the highest BMI quintile was substantially higher for Union Army veterans than for those in the NHANES-I survival sample. This is especially the case in Model 4, 5, and 6, where deaths in the first five years of follow-up have been excluded. As the results from Model 5 in the Union Army survival sample indicate, the mortality risk for those veterans who were in the highest BMI quintile is 1.40 (=exp(0.338)) times the average overall mortality risk, holding constant the other explanatory variables. This effect is statistically significant. The corresponding figure in the NHANES-I survival sample is 1.13 (=exp(0.126)) times.

I now come to explain the effects of the other explanatory variables on the hazard rate of dying during the 18 years of follow-up.

Firstly, the role of height seems not so salient as that of BMI in predicting survival after fifties. This is especially the case for the Union Army survival sample. Height virtually had no impact on mortality risk in Model 2 and 5, after the effect of BMI and age at examination had been controlled. This is consistent with John Murray's finding that while BMI has a significant impact on mortality, the effect of height is not significant when predicting survival among the Amherst College students (Murray, 1997). In the NHANES-I survival sample, the effect of height becomes notable (although still not statistically significant), indicating that taller people on average had lower mortality risk. For example, the coefficient of '-.039' from Model 5 means that, after deaths in the first five years of follow-up have been excluded, for each additional inch of height at examination, mortality risk becomes 3.8 percent (=1-exp(-.039)) less, controlling for the other explanatory variables in the model.

Secondly, between age 50 and 59, higher age at examination leads to higher mortality risk. The effect is statistically significant in all the six models in the Union Army survival sample, but not in the NHANES-I survival sample. For example, as the results from Model 1 in the Union Army survival sample indicate, for each additional year in age at examination, mortality risk will on average be increased by 10 percent (=exp(0.098)-1)), controlling for the other independent variables. The corresponding figure from Model 1 in the NHANES-I survival sample is 3 percent (=exp(0.031)-1)).

Thirdly, results from Model 3 and Model 6 in the Union Army survival samples indicate that those who were farmers at enlistment enjoyed a significantly lower mortality risk than those who were not. For example, based on Model 3 in the Union Army survival sample, to be a farmer is associated with 25 percent less mortality than non-farmers, after BMI, height, and age at examination all having been controlled. There have two plausible explanations for the survival advantages of farmers. One is that prior to the 20th century, food availability and food quality was better in rural areas than in urban areas. The other is the less exposure to infectious diseases in rural areas than in urban areas (Wilson and Pope, 2003; Lee, 2003).

Finally, in the NHANES-I survival sample, being married is associated with a substantial survival advantage. For example, results from Model 3 in the NHANES-I survival sample suggest that for those who were married at the examination, their mortality risk is only half of those who were not married (mostly divorced or widowed) at the examination, after all the other independent variables in the model having been controlled. To what extent can this marriage advantage be attributed to marriage itself or to the selection effect of marriage needs further investigation.

3. Discussions and Conclusion

Adulthood BMI is persistently relevant in predicting old age survival. In general, the U-shaped association between BMI and old age mortality observed in the Union Army survival sample still holds today. For white male Americans, no matter they lived in the late 19th century or in the early 1970s, to have an optimal BMI in their fifties implies, on average, at least 20.8 percent[9] lower mortality risk in the following 18 years than the overall average level. Given the robustness of the optimal BMI across six different models in both samples, it can be safely inferred that a more compact BMI distribution, centered by optimal BMI, will no doubt decrease old age mortality substantially.

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[9] The lowest value associated with optimal BMI in the eight models listed in Table 4 and Table 5.

Despite this general persistence, considerable changes have taken place in the association between BMI and old age survival among white male Americans since the late 19th century. Two of these changes are remarkable.

One is that optimal BMI has experienced a substantial upward shift, from 20.4-22.0 in the Union Army survival sample to 24.9-26.9 in the NHANES-I survival sample. This suggests that the optimal BMI associated with old age survival is historically dynamic, rather than stable. With the whole American population having moved into a higher BMI regime, the optimal BMI also shifted upwardly. Correspondingly, if we use the BMI-mortality association derived from the Union Army survival sample to predict the future old age mortality for today's white male Americans, we will overestimate it.

The second intriguing change is that the mortality penalty associated with the highest BMI quintile today becomes less severe than a century ago, although the higher mortality risk is still present. This is especially the case when deaths in the first five years have been excluded from the NHANES-I survival sample. How to account for this change? A direct observation is that in the Union Army survival sample, those in the highest BMI quintile are further away (in relative terms) from the optimal BMI (2^{nd} quintile) than their counterparts from the NHANES-I survival sample. Another plausible explanation lies in the more successful medical interventions to obesity-related diseases in contemporary America. Modern medical technologies such as use of antibiotics, complicated cardio-surgeries, surgical anesthesia, radiographs etc. were not even in the mind of doctors in the 19^{th} century. Americans with obesity today also have more options to control or lose weight than those a century ago, from simple caloric intake control, more exercise, to even getting rid of adiposity through surgeries. Weight loss has actually become a big industry in modern United States.

The finding that the lowest BMI quintile in the NHANES-I survival sample is associated with significantly higher mortality risk than their counterparts in the Union Army survival sample calls for more attention. The factors behind underweight might be different between the two samples. In a low BMI regime, underweight, to a large extent, can be viewed as the result of malnutrition. By contrast, in a high BMI regime where Engel's coefficient is unprecedentedly low, underweight might be more of a result of certain types of diseases or life style factors such as smoking. The detailed reasons are in need of further investigation.

To take the upward trend of BMI into account, the findings revealed in the comparative survival analysis have implications to the future trend in old age survival among white male Americans. Firstly, and most importantly, there is still good potential for old age mortality to further decline among today's white male Americans. To forecast future mortality changes is challenging, and there is no doubt BMI does not tell everything. A historical investigation of the BMI-mortality association as I did above, however, does provide some insight into the problem. The finding that optimal BMI in one's fifties is associated with a 30 percent lower mortality risk than the overall average level in the NHANES-I survival sample, implies that if the BMI distribution can be narrowed down to where the optimal BMI is located, there will be a substantial mortality decline. 74.5 percent in the NHANES-I survival sample are out of the optimal BMI (24.9-26.9), with 39.0 percent below it and 35.5 percent above it. The corresponding percentage for today's white male Americans who are in their fifties is 79.3 percent, with 22.7 percent below it and 56.6 percent above it. This tends to suggest that the BMI distribution among today's white male Americans has become less favorable to old age survival than that in the early 1970s, if we assume that the optimal BMI observed in the NHANES-I survival sample still holds today.

Secondly, to a certain extent, the future old age mortality for white male Americans also depends on the role of obesity in old age survival. Since the early 1970s, the average age-adjusted BMI for ages between 25 and 74 has increased from 25.9 to current 28.0 (as indicated in Table 2). At the same time, the age-adjusted percentage of obesity has increased from 12.2 to 28.2, a 131 percent increase. Given this dramatic increase in the prevalence of obesity, the non-significant negative effect associated with the highest BMI quintile on old age survival in the three models (4 to 6) in the NHANES-I survival sample might not hold any more. Even if the effect stays non-significant today, for which only time can tell, the detrimental effect of obesity on morbidity and mortality, and the corresponding economic cost still cannot be ignored. It has been estimated that the total cost attributable to obesity in the United States in 1995 amounted to $ 99.2 billion, out of which approximately $ 51.6 billion were direct medical cost associated with diseases attributable to obesity (NIH, 1998). The fact that we are spending more money fighting against the obesity epidemic does not necessarily mean we have become more capable to control it. Before the potential of a further decrease in old age mortality can be developed, an inquiry into the socio-economic factors behind the current unfavorable BMI distribution becomes necessary.

References

Allison, D.B.; Gallagher, D.; Heo, M.; Pi-Sunyer, F.X. and Heymsfield, S.B. " Body Mass Index and All-Cause Mortality among People Age 70 and over: the Longitudinal Study of Aging." *International Journal of Obesity*, June 1997, 21(6), pp. 424-431.

Allison, D.B.; Zhu, S.K.; Plankey, M.; Faith, M.S. and Heo, M. "Differential Associations of Body Mass Index and Adiposity with All-Cause Mortality among Men in the First and Second National Health and Nutrition Examination Surveys (NHANES-I and NHANES Π) Follow-Up Studies." *Int J Obes Relat Metab Disord.* , March 2002, 26(3), pp. 410-416.

Bender, R.; Jockel, K. H.; Trautner, C.; Spraul, M. and Berger, M. "Effect of Age on Excess Mortality in Obesity." *JAMA*, April 28, 1999, 281(16), pp. 1498-1504.

Bray, George A.; Bouchard, Claude and James, W.P.T. *Handbook of Obesity*, New York: Marcel Dekker, Inc., 1998.

Calle, Eugenia E.; Thun, Michael J.; Petrelli, Jennifer M.; Rodriguez, Carmen and Health, Clark W. Jr. " Body-Mass Index and Mortality in a Prospective Cohort of U.S. Adults." *The New England Journal of Medicine*, October 7,1999, 341(15), pp.1097-1105.

Cornoni-Huntley, J.C.; Harris, T.B.; Everett, D.F.; Albanes, D.; Micozzi, M.S.; Miles, T.P. and Feldman, J.J. " An Overview of Body Weight of Older Persons, Including the Impact on Mortality. The National Health and Nutrition Examination Survey I--Epidemiologic Follow-Up Study." *Journal of Clinical Epidemiology*, 1991, 44(8), pp. 743-753.

Costa, Dora L. "Height, Weight, Wartime Stress, and Older Age Mortality: Evidence from the Union Army Records." *Explorations in Economic History*, 1993, 30,pp. 424-449.

Costa, Dora L. and Steckel, Richard H. " Long-Term Trends in Health, Welfare, and Economic Growth in the United States." NBER Working Paper Series on Historical Factors in Long Run Growth. National Bureau of Economic Research (Cambridge, MA) Historical Paper No.76, November 1995.

Costa, Dora L. (editor) *Health and Labor Force Participation over the Life Cycle: Evidence from the Past.* The University of Chicago Press 2003.

Diehr, P.; Bild, D.E.; Harris, T.B.; Duxbury, A.; Siscovick, D. and Rossi, M. “ Body Mass Index and Mortality in Nonsmoking Older Adults: the Cardiovascular Health Study.” *American Journal of Public Health*, April 1998, 88(4), pp. 623-629.

Dorn, J.M.; Schisterman, E.F.; Winkelstein, W. Jr. and Trevisan, M. “ Body Mass Index and Mortality in a General Population Sample of Men and Women. The Buffalo Health Study.” *American Journal of Epidemiology*, December 1, 1997, 146(11), pp. 919-931.

Durazo-Arvizu, R.A.; McGee, D.L.; Cooper, R.S.; Liao,Y. and Luke, A. “ Mortality and Optimal Body Mass Index in a Sample of the US Population.” *American Journal of Epidemiology*, April 15,1998, Vol.147, Issue 8, pp. 739-749.

Engeland, Anders; BjØrge,Tone; Selmer, Randi Marie; Tverdal, Aage. “ Height and Body Mass Index in Relation to Total Mortality.” *Epidemiology*, 2003,14(3), pp. 293-299.

Field, Alison E.; Coakley, Eugenie H.; Must, Aviva; Spadano, Jennifer L. and Laird, Nan. “ Impact of Overweight on the Risk of Developing Common Chronic Diseases During a 10-Year Period.” *Arch Intern Med.*, July 2001, Vol. 161, pp. 1581-1586.

Fogel, Robert William. “ Nutrition and the Decline in Mortality Since 1700: Some Preliminary Findings.” Pp. 439-555 in *Long-Term Factors in American Economic Growth*, edited by S.L. Engerman and R.E. Gallman. Chicago: University of Chicago Press, 1986.

Fogel, Robert William. “Economic Growth, Population Theory, and Physiology: the Bearing of Long-Term Processes on the Making of Economic Policy.” Nobel Lecture. December 9,1993.

Fogel, Robert William and Costa, Dora L. “ A Theory of Technophysio Evolution, with Some Implications for Forecasting Population, Health Care Costs, and Pension Costs.” *Demography*, February 1997,34(1), pp. 49-66.

Fogel, Robert William. “ Catching up with the Economy.” *The American Economic Review*. March 1999, Volume 89, Issue 1, pp.1-21.

Fogel, Robert William. Grant Proposal (2000).

Fontaine, Kevin R.; Redden, David T.; Wang, Chenxi; Westfall, Andrew O. and Allison, David B. “ Years of Life Lost Due to Obesity.” *JAMA*, January 2003, 289(2), pp. 187-193.

Grabowski, David C. and Ellis, John E. “ High Body Mass Index Does Not Predict Mortality in Older People: Analysis of the Longitudinal Study of Aging.” *Journal of* *the American Geriatric Society*, 2001, 49, pp. 968-979.

Greenberg, J.A. " Biases in the Mortality Risk Versus Body Mass Index Relationship in the NHANES-1 Epidemiologic Follow-Up Study." *Int J Obes Relat Metab Disord*, July 2001, 25(7), pp. 1071-1078.

Himes, Christine L. " Association between Body Size and Mortality in Later Life." Aging Studies Program Paper No.21. Syracuse: Center for Policy Research, Maxwell School of Citizenship and Public Affairs, June 2000.

Komlos, John. *Stature, Living Standards, and Economic Development*. Chicago and London: The University of Chicago Press, 1994.

Komlos, John. *The Biological Standard of Living in Europe and America, 1700-1900*. VARIORUM, 1995.

Komlos, John and Baur, Marieluise. "From the Tallest to (One of) the Fattest: the Enigmatic Fate of the American Population in the 20th Century." Discussion Paper 2003-19 at the Department of Economics, University of Munich, July 2003.

Landi, F.; Zuccala, G.; Gambassi, G.; Incalzi, R.A.; Manigrasso, L.; Pagano, F.; Carbonin, P. and Bernabei, R. " Body Mass Index and Mortality among Older People living in the Community." *Journal of the American Geriatric Society*, September 1999, 47(9), pp. 1072-1076.

Lee, Chulhee. "Prior Exposure to Disease and Later Health and Mortality: Evidence from Civil War Medical Records". In *Health and Labor Force Participation over the Life Cycle: Evidence from the Past,* 51-88. Edited by Dora Costa. Chicago, The University of Chicago Press 2003.

Lee, I. M.; Manson, J. E.; Hennekens, C.H. and Paffenbarger, R. S. Jr. " Body Weight and Mortality. A 27-Year Follow-up of Middle-age Men." *JAMA*, December 15, 1993, 270(23), pp. 2823-2828.

Murray, John E.. "Standards of the Present for Peoples of the Past: Height, Weight, and Mortality among Men of Amherst College, 1834-1949. *The Journal of Economic History*, September 1997, 57(3), pp. 585-606.

Lindsted, K.; Tonstad, S. and Kuzma, J. W. " Body Mass Index and Patterns of Mortality among Seventh-day Adventist Men." *International Journal of Obesity*, June 1991, 15(6), pp. 397-406.

National Institute of Health. *Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults: The Evidence Report.* NIH

Publication No. 98-4083. September 1998.

Steckel, Richard H. "Stature and the Standard of Living." *Journal of Economic Literature*, December 1995, Vol. 33, Issue 4, pp. 1903-1940.

Stevens, June; Cai, Jianwen; Pamuk, Elsie R.; Williamson, David F.; Thun, Michael J. and Wood, Joy L. " The Effect of Age on the Association Between Body-Mass Index and Mortality." *The New England Journal of Medicine*, January 1,1998, 338(1), pp. 1-7.

Tayback, Matthew; Kumanyika, Shiriki and Chee, Elsbeth. " Body Weight as a Risk Factor in the Elderly." *Arch Intern Med.*, Vol. 150, May 1990, pp. 1065-1072.

Taylor, DH. Jr. and Ostbye, T. "The Effect of Middle- and Old-Age Body Mass Index on Short-term Mortality in Older People." *Journal of the American Geriatric Society*, October 2001, 49(10), pp. 1319-1326.

Tsugane, S.; Sasaki, S. and Tsubono, Y. "Under-and Overweight Impact on Mortality among Middle-age Japanese Men and Women: A 10-y Follow-Up of JPHC Study Cohort I." *Int J Obes Relat Metab Disord.* , April 2002, 26(4), pp. 529-537.

Ulijiaszek, S.J. and Mascie-Taylor, C.G.N. *Anthropometry: the Individual and the Population*. Cambridge University Press, 1994.

U.S. Dept. of Health and Human Services, National Center for Health Statistics. NATIONAL HEALTH AND NUTRITION EXAMINATION SURVEY I: EPIDEMILOGIC FOLLOW-UP STUDY, 1992 [Computer file]. Hyattsville, MD: U.S. Dept. of Health and Human Services, National Center for Health Statistics [Producer], 1996. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2000.

Waaler, Hans Th. " Height,Weight and Mortality: The Norwegian Experience." *Acta Medica Scandinavica*, Supplementum 679, 1984.

Wilson, Sven E. and Clayne L. Pope. "The Height of Union Army Recruits: Family and Community Influences". In *Health and Labor Force Participation over the Life Cycle: Evidence from the Past,* 113-46. Edited by Dora Costa. Chicago, The University of Chicago Press 2003.

World Health Organization. *Obesity: Preventing and Managing the Global Epidemic. Report of a WHO Consultation of Obesity.* Geneva, 3-5 June 1997.